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GEOPHYSICS.—*Shaping the earth.*[1] WILLIAM BOWIE, United States Coast and Geodetic Survey.

THE CRUST OF THE EARTH

It is generally recognized that the earth has had a surface of solid material for something like a billion and a half years. At the beginning of this time, the earth's surface was irregular and there have been vertical and horizontal changes occurring continuously during this long interval. These changes have been due to erosion and sedimentation and to forces which are acting on the materials forming the outer fifty or one hundred miles of the earth.

If the earth's material were in a liquid or highly plastic condition, and if there were no rotation, its surface would be a true sphere. With such a body undergoing rotation, the surface would be a spheroid. It has been found by geodetic measurements that the shape of the mean sea level surface approximates very closely a true spheroid. The deviations between the spheroid and the water surface, or geoid, are probably not greater than 100 meters. These forms are, of course, due to the continuous gravitational attraction of the particles of the earth for each other. The earth's surface is irregular because of the presence of material of different densities near the earth's surface. Under the continents the densities are less than they are for the material under the oceans. There is rigidity in the outer portion of the earth for otherwise there would be a slumping down of the high areas and the moving material would fill up valleys and ocean basins and bring the earth's surface to a true spheroid.

[1] Presidential address delivered before the ACADEMY, January 15, 1931. Received February 9, 1931.

FORMATION OF OCEANS AND CONTINENTS

One of the most interesting problems of geology involves the formation of oceans and continents. Some geologists will say that this is a subject that need not be considered for we may accept oceans and continents as having come into being prior to the present geological age and that our attention should be given to the problem of unfolding the geological record since the beginning of sedimentation. The mind of a human being cannot be confined to any particular subject or group of subjects nor to any particular phase of a subject. It is bound to consider any question that presents itself.

It does seem very strange that we should have great masses of material standing above sea level, as continents and islands, and great troughs or basins below the waters of the oceans. We have enough geodetic evidence to prove conclusively that the ocean bottoms are depressed because of the greater density of the material in the crust below them, and that the continental and island masses stand above sea level because the density of the material in the crust below them is less than normal; but how could these abnormal densities have arisen? Why is it that under the continents we have a layer, which some claim is about twenty miles in thickness, of light rocks called granites, while under the oceans we have no granites?

There have been many explanations offered as to why we have oceans and continents, but the only one that appeals to me as having decided merit is that advanced by Osmond Fisher. About forty years ago he wrote a book entitled, "Physics of the Earth's Crust," which contains much material of great value. He has a chapter on the possible erosion of oceans and continents in which he discusses Darwin's idea that the moon at one time was thrown off from the earth. Darwin's discussion of the birth of the moon was more or less an academic one and he made no suggestion as to what was the condition of the earth at the time that this birth occurred, but one is led to believe by Darwin's writings that he had in mind a fluid earth. Fisher believed that there was an outer solid shell on the earth at the time that the moon was formed and that the earth lost much of the outer granite shell at that time. The places from which the crustal material was thrown off were filled with sub-crustal material, but the light granite occupied greater depth than the heavier sub-crustal material which replaced it. In consequence, the healed scars had surfaces which were lower than the surfaces of the portions of the crustal material which remained.

Darwin's hypothesis is based on the idea that the earth was rotating

very rapidly and that as it slowed down to such a rate of rotation as would make the tides, caused by the attraction of the sun, synchronize with the natural period of vibration of the earth, there would be an accumulation of tidal effect which would make the earth's mass unstable. Darwin estimated that at the time of, or just before, the disruption, the major axis of the earth was about twice the length of the minor axis. This would mean that the earth's surface must have been increased by approximately fifteen millions of square miles. The solid crust, which at the time of the birth of the moon must have been thirty or forty miles in thickness, could not have stretched over this increased surface but would have been fractured and torn apart with great gaps between the crustal blocks. It may be that this distortion just prior to the birth of the moon had more to do with the scattering of the remaining crustal material over the earth's surface than the actual disruption.

It is rather interesting to look at a globe and note that the two coasts of the Atlantic are so nearly parallel that they remind one of the shores of a great river. Wegener has advanced a theory that North and South America broke away from the rest of the continental masses and moved westward during recent geological times. This is a very interesting theory which has many advocates and also many opponents. I am rather inclined to think that there are difficulties in the Wegener hypothesis which are very hard to explain away. It seems to me that the Fisher idea of the birth of the moon gives us a rather logical explanation of the creation of oceans and continents, and the strongest point of this theory is that it does no violence to isostasy.

It is certain that the earth's surface was irregular at the beginning of the sedimentary age, for without irregularities, such as we now have, the water of the oceans would have covered the whole earth's surface to a depth of approximately 9,000 feet if the amount of water was the same as now. With all of the land area covered by water, there could have been no erosion and sedimentation, such as we have had for a period of approximately one and one-half billions of years.

KNOWN FACTS ABOUT THE EARTH

The earth should be treated like any material structure which comes under our observation for explanation or analysis. No one, of course, can give us the true explanation of how the earth came into being or state accurately what has been going on to change its surface configuration. But we have now at hand a number of facts which should enable us to arrive at some logical conclusions. We know, of

course, the earth's shape and size, the portions of its surface covered by land and water, its average density, and the density of its surface material. We also know that the temperature increases with depth. We know that there are many earthquakes occurring annually and that there is no area which is entirely free from them. Most of the quakes are microscopic in their intensity, but we are reasonably certain that, with few exceptions, they result from breaking rock and, therefore, there must be forces within the earth large enough to cause such breaking.

We know that there has been a tremendous amount of erosion and sedimentation during the present era, which is called the sedimentary age of the earth. It is certain that the earth's surface was irregular at the time that sedimentary rocks began to be formed, for without an irregular surface there could have been no running water, and without running water there could have been no erosion and sedimentation. Of course, no one knows whether the amount of water that is on the earth has been constant or variable, but it is reasonably certain that land has been exposed above the waters of the ocean for about a billion and a half years. This is an estimate that is frequently used by students of the earth and it seems to be generally accepted as of the order of magnitude of the period of time that has elapsed since the formation of the first sedimentary rocks.

Geologists tell us that practically all of the exposed areas of the earth have at some time in the geological past been below sea level. These areas are now at varying distances above sea level and, hence, their change in elevation, with respect to sea level, must have been due to an actual lifting up of the land areas rather than a decrease in the amount of water of the earth. If the latter had been the cause for the changes in elevation, there would be uniformity in the elevations of exposed strata.

The isostatic investigations indicate that the solid or rigid material of the earth extends only to a depth of approximately 60 miles below sea level. Some investigators are of the opinion that the depth to which the solid rock extends is very much smaller than that. The interior of the earth acts as if it were plastic to long continued stresses. The earth has an outer shell which rests upon a plastic interior. A disturbance of the isostatic equilibrium leads to horizontal and vertical changes in the earth's surface. Some areas go down under the weight of sediments and other areas which have been undergoing erosion for long periods of time increase in elevation. There is also a rising up of

material that was once below sea level and a sinking down of areas which were once standing high above sea level.

These and other known facts regarding the earth are the basis for the interpretation of the processes which have shaped its surface.

There have been many theories advanced as to why the earth has an irregular surface. Such theories may be considered as mere guesses, for no one can reproduce today the forces, resistances and temperatures which must have been involved when the earth came into being or when its surface was changed from one of fairly uniform elevation to one which has the great differences in elevation that are seen today.

Mineralogists tell us that the continents are underlaid by granite, and that granite is absent from the crust under the ocean. Granite has a smaller density than that of the basalts which underlie the oceans. Originally the earth must have had the granite or light material lying over its surface like a huge blanket of fairly uniform thickness. Why is it that now the granite is absent from such large portions of the earth's surface? There are certainly no known forces that could push the granite up into isolated masses. Gravity would have resisted such piling up and if forces had been sufficiently great to force the granite into separate masses, these masses of crushed rock would have slumped down soon after the forces had ceased to operate.

ISOSTASY

It was a geologist, the famous C. E. Dutton of the United States Geological Survey, who coined the word *isostasy* in an address, entitled *On some of the major problems of physical geology*, at a meeting of the Philosophical Society of Washington in 1889. Dutton discussed some of the major problems of geology, including, of course, the formation of mountains and the effect of the tremendous amount of erosion and sedimentation. He came to the conclusion that the shifting of material caused stresses which could not be withstood by the strength of the earth's materials. He felt that there must be a sagging down of the earth's surface under the weight of the sediments and a rising up of the surface where erosion had carried material away. He stated that in his opinion mountains are not extra loads added to the earth's crust but that they are due to lighter than normal material in the crust below them. In effect he outlined what might be called a flotation hypothesis, that is, that the continents were floating in heavier material just as ice floats in water. A corollary of this hypothesis of Dutton's is that the irregularities of the earth's surface are due to deviations from normal densities in the outer portion of the earth.

Under the oceans the density is greater and under the continents less than normal.

At the beginning of the present century geodesists realized that isostasy was a subject of vital interest to them. Previously, for decades, they had been attempting to explain the abnormal behavior of the plumb line to which astronomical observations are referred and of the pendulum by which values of gravity are determined.

THE FIGURE OF THE EARTH

If the earth's surface had no irregularities but conformed to a mathematical surface (an ellipsoid), then at any place on it the direction of gravity would be at right angles to a plane tangent to this ellipsoid at the point of observation. But the earth has an irregular surface and due to this irregularity the figure formed by the surfaces of the waters of the ocean and of the waters of sea level canals extended, in imagination, through the continents deviates from a true mathematical figure. This deviation is undoubtedly a maximum under the great mountain systems like the Himalayas and the Alps where the geoid, or water surface, is above the mathematical one. Conversely over the deepest parts of the ocean the geoid, or water surface, is probably depressed to the maximum amount below this spheroid. In any event, there is an angle between the water surface and the mathematical surface at any point at which astronomical observations may be made. This angle means a deviation of the direction of gravity, or the plumb line, and affects the observations for astronomical latitudes and longitudes accordingly.

EFFECT OF TOPOGRAPHY ON GEODETIC DATA

Geodesists had noticed this condition in a number of parts of the earth where surveying and mapping operations had been undertaken, and efforts were made to apply a correction for the influence of the irregularities of the surface. It was evident to each investigator that a mountain system, such as the Himalayas, would have an attractive effect on the plumb line at stations within a reasonable distance of it. Efforts were made to compute the effect of these great masses which lie above sea level, but when such corrections were applied it was found that they were larger than were necessary to bring the theoretical and observed values into accord. The mountains, apparently, were lighter than normal but impossibly small densities would have to be assumed for the materials composing the mountains to bring the two values into exact agreement.

Pratt and Airy working on geodetic data about the middle of the last century arrived at the conclusion that the reason why mountains and continents stand above sea level is because lighter materials lie below them. While they did not, so far as I am aware, make any definite statement that the abnormal densities could only extend to a moderate depth, yet this idea was implied in their statements regarding the deficiencies in densities that must lie below mountains and continents. They advanced their ideas about seventy-five years ago but it is only within the last ten years that their ideas and those of Dutton, expressed forty-one years ago, have been accepted generally by students of the earth as a working principle in earth studies.

VARIATIONS OF GRAVITY

Geodesists have used geodetic data in the form of triangulation, of astronomical determinations of longitude and latitude, and of values of gravity to test this flotational hypothesis. It is the only method, so far as I am aware, by which the idea can be quantitatively tested. We have a direct measure of the extent to which the plumb line deviates from the line that is at right angles to the spheroid surface, and a measure of the difference between the theoretical and observed values of gravity. The idea of isostasy can be tested by means of these data.

If the earth were a true spheroid and there were no irregularities on its surface and if the densities along each radius were normal, gravity would increase slightly as one proceeded from the equator to one of the poles. The attraction of the earth at sea level would be about 1/200 part greater at a pole than at the equator. Enough work has been done to prove conclusively that gravity does follow very definite laws. For instance, it changes on the average about one part in a million for a mile change in latitude. It changes one part in a million for about 10 feet change of elevation. These changes are perfectly normal, for the centrifugal force is a maximum at the equator and zero at the poles and, besides, the attraction at either pole is greater than it is at a point on the equator. Necessarily, too, a particle is attracted less by the mass of the earth when elevated than when it is exactly at sea level.

It is not necessary to go into details regarding the geodetic tests of isostasy, for the methods used and the results obtained have all been set forth in a number of publications of geodetic organizations. It is sufficient to state that when isostasy is taken into account in computing geodetic data, harmonious or practically harmonious results are

obtained. By means of geodetic data it has been possible to determine the approximate depth below sea level to which these abnormal densities extend. The most probable depth obtained from mountain and plateau stations of the United States is about 96 kilometers, approximately 60 miles, below sea level. This depth is confirmed by determinations of Mr. A. H. Miller of the Dominion Observatory at Ottawa, Canada, who found from analysis of gravity data at mountain stations in the western part of that country a depth also of approximately sixty miles.

COMPARISON OF PRATT AND AIRY HYPOTHESES

There has been much discussion in literature on isostasy of the question as to whether the Pratt or the Airy hypothesis is the true one. Pratt postulated that the densities vary under the different classes of topography. Under the oceans, the density would be abnormally great, and under the continents, it would be abnormally small. Airy, on the other hand, suggested that the depth of compensation is very irregular and that crustal masses under the continents extend much farther below sea level than do such masses under the oceans. Under mountain areas these protuberances would be greater than under plateaus and valleys.

We have not yet been able to prove which of the two hypotheses is the true one, since the application of either of them to gravity and deflection data gives about the same satisfactory results. However, looking at the matter from a purely physical standpoint, I am inclined to think that there are decided weaknesses in the Airy hypothesis and that the Pratt hypothesis is probably the true one. Perhaps with a greater accumulation of data we may in the future be able to show which one of these hypotheses is the better one. We should be able to derive a depth of compensation for each extensive mountain area and if the Airy hypothesis is the true one, then the higher the mountain area the greater should be the derived depth of compensation. When such mountain areas as the Andes and the Himalayas are covered by geodetic stations, it should be possible to make this test.

ASSUMPTIONS UNDERLYING ISOSTATIC INVESTIGATIONS

Necessarily, in carrying on such investigations as have been involved in the tests of isostasy, assumptions have to be made. The assumptions made by geodesists are approximately as follows: First, that isostasy is complete or perfect for even quite limited portions of the earth's crust; second, that there is a uniform distribution with respect to depth of the compensating deficiencies of density under continents

and of the excesses of densities under oceans, that is, that the compensation starts at sea level and extends uniformly approximately sixty miles to the lower limit of the crust; third, that the compensation is directly under the topographic feature and not spread out horizontally with respect to that feature; and fourth, that the density of the rock above sea level is 2.67.

These assumptions are made merely for the convenience of the investigator. It would be practically impossible for him to assume anything but very simple conditions because of the very large amount of work involved in making the computations required for the tests. We do find that when these assumptions are made and corresponding corrections computed that the theoretical and actual values for the astronomical longitudes and latitudes and for values of gravity are brought very closely into agreement. There are some outstanding differences, and these must be a measure of the degree to which one or more of the assumed conditions are not true. The depth of compensation may not be a regular surface, it may be very much deeper under some parts of the continent than under others, and it may be deeper under the continents than under the oceans. The compensating deficiency of density under a mountain system may be confined to a rather narrow zone vertically and not extend throughout the thickness of the crust. The compensation may be distributed widely in a horizontal direction from the topographic feature, and deficient densities under land masses and excessive densities under ocean areas may not be sufficient to balance the irregularities of the earth's surface in the regions studied. Finally, the density of surface rock is variable. Undoubtedly, all of these factors come in to cause the differences between the theoretical and actual values which we call anomalies, but the anomalies are so small after the isostatic principle has been applied that investigators are inclined to believe that the principle of isostasy has been amply tested and proved. Some of them, and I am one, believe that the principal cause of the anomalies is the effect of abnormally heavy or light material near the earth's surface and close to the astronomical or gravity stations. If we could find out the actual distribution of density in the earth's materials for a depth of five or ten miles below the earth's surface, I am confident that we could reduce nearly all of the anomalies.

This brings up the question as to whether or not it would be possible to discover what the geologists call *structural features* that are buried below the earth's surface. This is a matter of great importance and may have a bearing on the search for petroleum and ores. The gravity survey conducted over this country indicates certain places where there

are extra heavy or extra light masses of material fairly close to the earth's surface. I do not know of any oil having been found, or drilling for oil having been undertaken, near any of our gravity stations as a result of our data, but I am sure that an intensive gravity survey would disclose structure that might be of value in the oil and mining industries.

SOME ISOSTATIC CONCLUSIONS

The evidence seems to justify the conclusion that all mountain and plateau areas were at one time occupied by low lying portions of the earth's surface on which great beds of sediments were laid down. Then these areas were raised up to form either mountains or plateaus. If there was much distortion, mountains resulted, and if the area went up in a more or less uniform way, extensive plateaus were formed. What caused these uplifts is one of the outstanding problems of the science of geology. Many of the investigators of the past have postulated horizontal thrusts, while some, Dutton included, were inclined to favor a vertical movement as the predominant one with horizontal movements as incidental.

It is absolutely certain that the masses pushed up, whether by vertical or horizontal forces, are not extra loads added to the surface at what may be called the depth of isostatic compensation. These masses above sea level are, of course, extra loads on the sea-level surface, but they cannot possibly be extra loads added to the imaginary blocks of the earth's crust which are resting on the plastic sub-crustal material. If they were extra loads, this fact would be easily and clearly indicated by geodetic data in the form of deflections of the vertical and values of gravity. The masses that appear above sea level are compensated for by the deficiency of density in the material lying below them.

The zone within which the compensation of topographic features lies must be of limited depth. If it were otherwise, the computed effect of the compensation would be practically zero and the material above sea level would have full effect on the direction and force of gravity.

It has been concluded from a study of the deflection data for the United States that the actual deflections of the vertical are on the average not more than about 10% of what they would be if the masses above sea level and the deficiency of the mass in the oceans were not compensated by deviations from normal densities in the crust below. This is the very strongest evidence possible in favor of

isostasy and, also, in favor of the theory that the outer portion of the earth is rigid and strong. This rigid material, which has been found by geodesists to extend to an average depth of approximately sixty miles, will resist for extremely long times gravitational forces which tend to make the earth's surface a true spheroid. The gravity data supplement the data derived from the deflection of the vertical in showing the existence of isostasy.

Since areas of sedimentation and erosion and all plateau and mountain regions are now in isostatic equilibrium, it seems reasonably certain that they have been in equilibrium throughout the geological era. If this is true, we must conclude that there has been an actual uplift of the surface in some places and a down warping in others. These changes in the earth's surface can occur only by vertical movements, due to changes in the density of the crustal or sub-crustal material, or to the action of horizontal forces. I am inclined to favor the former idea because it is rather difficult to see where horizontal forces of sufficient magnitude could originate. Since the sea level surface of the earth is at all places at right angles to the direction of gravity, it is difficult to see how any large horizontal component of the gravitational force could come into existence.

I believe that there has been no collapsing of the outer shell of the earth on a shrinking nucleus. The outer solid shell of the earth must be of the magnitude of sixty miles in thickness and certainly at such a depth as sixty miles there could be no voids; the outer shell, or crust, of the earth must be in intimate contact with sub-crustal material and, therefore, there is no opportunity for the crustal material to collapse on a shrinking interior. Should the interior of the earth be losing heat and contracting in consequence, and should the crust of the earth not be losing heat and, therefore, remaining constant in volume, it is probable that the crust merely thickens locally as the nucleus contracts. Any changes in the volume of the nuclear material would be so exceedingly slow that the crustal material would yield locally and the crust would continue to be in contact with the nucleus around the whole earth.

ISOSTATIC ADJUSTMENTS AND EARTHQUAKES

If we accept the principle of isostasy, and it is a perfectly logical thing to do, then we are confronted with the problem of how to apply this principle in geological studies and investigations. It is especially important to apply the isostatic principle to the question of earthquakes.

They have been occurring for a billion years, more or less, and probably they will continue to occur as long as the earth has sunshine and rain. An earthquake is caused by the breaking of the outer portion of the earth's material. Without the break there would be no elastic shock. Where the material of the earth is hard, brittle, and elastic, it will resist deformation due to a force acting on it until the force is greater than its strength and there will be a sudden yielding in the form of a rupture. Any elastic substance necessarily has vibrations when it is struck or broken, and that is exactly what happens to the earth when we have an earthquake. The rock is snapped or broken, and the elastic waves set up by the sudden rupture travel great distances.

Records of earthquake waves are made with an apparatus called a seismograph. There are many of these instruments scattered over the earth's surface and the number of earthquakes annually recorded on them has been recently estimated as 8,000. There are many quakes of such small intensity that their shocks are not received at the existing seismological stations. It is impossible to state how many earthquakes actually occur over the earth, but if I might make a guess, I would say from 30,000 to 40,000 a year.

One of the implications from the proof of isostasy is that the outer portion of the earth is much stronger than the materials that lie somewhat farther down. In order that the irregular surface of the earth may be maintained against the tremendous weight of masses of rock above sea level, this outer portion of the earth must be strong, that is, it must have a strength sufficient to prevent the continental masses slumping down and flowing into the ocean areas to fill up the basins. This strong material extends, according to geodesists, approximately sixty miles below sea level. Below that the material must be lacking in strength and rigidity. It must yield to forces without breaking. As great masses of material are moved over the earth's surface the balance of the crust is disturbed. The extra load caused by sediments must push down the crust beneath and this must force the sub-crustal material to move sidewise and some of it to push up the crust from where the eroded material came. The earth's crust is like a sheet of ice on a pond or on the Arctic Ocean. The crust lies quietly on the interior part of the earth until something happens to disturb the equilibrium. Although the crust of the earth is composed of strong material, the strength is finite, surely not great enough to withstand the weight of the tremendous loads that have been shifted on the earth's surface. It is, however, strong enough to main-

tain the irregular surface of the earth just because of the floating principle.

Earthquakes have occurred probably in all parts of the earth. One cannot make an accurate estimate of the maximum size of the portion of the earth's crust in which, throughout geological time, no earthquakes have originated, but we see all about us evidences of uplift or subsidence of the earth's surface. Each continent has above sea level much sedimentary rock which must have been formed below tidal waters. These rocks in many cases are much tilted, curved, broken and crushed. It is reasonably certain that there has been an uplift of the earth's surface rather than a decrease in the amount of ocean waters to cause these exposures. The best evidence that they have been pushed up is the fact that strata laid down in salt water in horizontal positions are now tilted at various angles from the horizontal. Then again, the same strata exposed in a number of widely separated places are found at different elevations above sea level. This it seems is an indication that there has been an actual uplift of the earth's surface. Every one who has engaged in mining operations knows of the tremendous amount of faulting that has occurred in the rocks. A coal seam will be followed for a certain distance and then it gives out. Later the same seam of coal may be found at a higher or lower elevation. The many fractures that are found in mines and at the earth's surface lead one to the very definite conclusion that there has been much shifting of material in the geological past. Each one of these shifts, or changes, where a fracture has occurred, has probably caused an earthquake.

The earth may be classified as a yielding body. It should not be classed as a failing structure. A soap-bubble or a glass ball, when subjected to stresses greater than its strength, will collapse, but it is impossible for the earth to collapse. The earth is like a solid rubber ball which will yield and change its shape to forces that are exerted upon it. The earth is a globe almost spherical, approximately 8,000 miles in diameter. The number of cubic miles of material in the earth is great, but this large globe yields in a surprisingly easy manner to the forces that are acting upon it.

OBJECTIONS TO THE CONTRACTION HYPOTHESIS

Geologists and other students of the earth have for generations sought for the forces which may have disturbed the earth. Many ideas have been advanced and some of them have had wide acceptance. One of these is that the earth's interior is losing heat rather rapidly,

while the outer portion of the earth, the crust, is maintaining its temperature. In consequence, there is a shrinkage of the interior of the earth and a collapse of the crust, which causes earthquakes and elevates mountains and plateaus. This process is also held by some to be the cause of oceans and continents. It seems to me that a careful analysis of this hypothesis will lead one to the conclusion that it cannot be true. The earth has been likened to an apple or potato. Every one knows that a baked potato or a baked apple has wrinkles in its skin. The contraction hypothesis implies that the nucleus of the earth is like the interior of the apple or potato and that the crust of the earth is like the skin, but the skins of the apple and potato have practically no weight, and, therefore, during the cooking the shrinkage of the interior, due to loss of moisture, makes the skin wrinkle to fit the reduced size of the interior of the apple or potato.

The crust of the earth certainly cannot be likened to the skin of the apple or potato. In the first place, the crust is about sixty miles in thickness and is composed of heavy rock. Then, again, this material is so heavy that no wrinkles could possibly form which would have voids under them like the voids under the wrinkles of the apple and potato. There can be no such thing as a buckling or crumpling of the earth's crust on a shrinking interior. If the interior of the earth is losing heat, while the crust of the earth is maintaining its temperature, the loss of this heat must be so exceedingly slow that there can be no chance for stresses to accumulate to such an extent as to cause great horizontal forces. I believe that if in the course of geological time, measured by hundreds of millions of years, the earth's interior should cool and contract, the crust would continue to be in contact with the interior and, therefore, the crust would merely be thickened rather than buckled into ridges and troughs. Much has been written against the contraction hypothesis, notably by Mellard Reade and Alfred Wegener.

DIASTROPHIC FORCES

There are no known forces which have their origin outside of the earth's material which can exert horizontal stresses on the crustal material of the earth of such strength as to form mountains and plateaus and cause earthquakes. It is true that the attractive forces of the sun and moon are exerted on the earth, and, since the portion of the earth that is nearest to the sun or the moon is attracted more than the material that is farther away, a stress is set up. This stress is not of sufficient magnitude, however, to rupture the material or to

make it move out of its normal place, except to the extent of a slight elastic deformation called the earth tide. These tide producing forces of the sun and the moon change phase every few hours as the earth turns on its axis.

I think we can eliminate the attractive effect of the sun and the moon as being the cause of any geological phenomena involved in mountain forming, earthquakes, etc. Of course, the time of an earthquake on an island or near the continental coast may be decided by an exceptional high or low water tide in the vicinity, but it is reasonably certain that the crustal material is brought nearly to the breaking point by some other cause and that the high or low tide supplies merely the small increment required to increase the stress beyond the breaking strength of the rock. The real causes of the major features of diastrophism must lie within the earth itself.

Much has been written in recent years about the effect of the heat resulting from radioactivity of certain minerals in the outer portion of the earth. This, it seems to me, may be a factor in earth movements, but I am inclined to think it is one of minor importance. In the first place, the radioactivity is largely confined to the granitic material which is supposed to be only from fifteen to twenty miles in thickness under the continents. There is no granite under the oceans, but some of the strongest earthquakes occur there and much of the ocean bottom is quite active from a geological standpoint. Broken ground with very steep slopes is found under the oceans, and many oceanic islands are due to volcanic activity. All of this implies that movements are going on in the crust under the oceans, and these surely cannot be due alone to the radioactivity of minerals. The basalts which are supposed to underlie the granites of the continental areas and to form the bottoms of the oceans have present in them some radioactive minerals but not in such large proportions as are present in the granites.

Again, we have the problem of accounting for physical or chemical activity that probably occurs even to the depth of sixty miles below sea level. Earth students, who have been writing on radioactive minerals and their effect on geological processes, are inclined to the opinion that the deep lying materials have practically no effect on surface changes.

If we eliminate forces existing outside of the earth, forces dues to the supposed contraction of the earth's nucleus and the collapsing of the crust, and forces due to the effect of radioactive minerals as major causes of earth movements, we must search for some other force that might be effective.

We know that the temperature of the earth increases with depth. For the first two miles or less we have definite data from the determinations of temperatures in wells. There is a great variation in the rate at which the temperature increases with depth, but a fair average is 50°C. per mile. The temperature certainly continues to increase below the two mile depth, for we have many active volcanos in the world which emit cinders and lavas having temperatures of 1000°C. or more. Such temperatures would be found at a depth of approximately twenty miles if the temperature gradient were about the same throughout that depth as it is near the surface. Whether the temperature keeps on increasing with depth down to the center of the earth, we cannot tell for there is no way to discover, even approximately, what the temperature may be at great depths. A material may be at a temperature, which at the surface would be its melting point or even its boiling point, yet it probably would act like a strong solid when confined by the great pressures which must exist at considerable depths. A very hot interior of the earth, if there is little change in temperature from one period of time to another, will not exert any decided influence on the configuration of the earth's surface. Change in heat, however, whether a decrease or increase, will exert force. It will cause expansion or contraction of materials, but the heat of the interior of the earth is changing so slowly that it cannot be a major cause of surface changes. One would be most unwise to assert that the heat of the interior of the earth, without any other influences acting, could not cause changes in elevation and geographic positions of points on the earth's surface, but, if this interior heat is a primary cause of surface movements, no one, so far as I am aware, has given a very clear explanation as to how the changes are effected. I am rather inclined to think that we may eliminate the heat of the earth's interior as the major cause of geological phenomena. This heat does affect those portions of the crust which are lowered by sedimentation or raised by erosion, but it is not the primary cause of surface movements. I believe we should look for something that is closer at hand and easier of understanding.

EROSION AND SEDIMENTATION

There is one process continuously active which is so simple that apparently its influence on surface phenomena has been ignored or even overlooked except by a few. This is the phenomenon of erosion. Vast quantities of water fall to the earth each year and presumably this has been going on continuously since the beginning of the sedi-

mentary age of the earth, the one that we are now in. According to the best geological and geophysical evidence, the earliest sedimentary rocks were formed about a billion and a half years ago. It is absolutely impossible for sedimentary rocks to be formed without running water, and to have running water there must be sloping ground. A succession of sedimentary rocks has been formed during the past billion and a half years and for hundreds of millions of years there have been living creatures on the earth, so it seems perfectly logical to assume that rainfall must have occurred during all of that period.

The average rainfall per year over the land surface of the earth is about thirty inches. Of course, there are regions where the rainfall is one hundred inches or more, but these areas are very restricted in size, and there are other areas, such as the great deserts, where there is no rain at all or only a very few inches. A rainfall of thirty inches a year amounts to about one mile in every two thousand years, and during the whole of the sedimentary age about 750,000 miles of rain could have fallen. This, of course, means that by evaporation and precipitation the ocean waters have been used over and over again. As the water of the ocean is evaporated, the mineral content remains in the ocean. When the water runs from the continental or island areas into the oceans it carries in suspension or solution some solid material. The solids are mostly in the form of salts. The mineral content of the ocean waters that we now observe has been caused by this process of evaporation and precipitation throughout the sedimentary age.

This transfer of water from the oceans to the continents and then back into the oceans would be of no consequence from a geological standpoint if it were not for the resulting erosion of the exposed surface of the earth. Much of the water runs directly to streams and rivers and eventually reaches tidal water, except in a few desert basins where the rivers have no outlet to the sea, but these latter are very unimportant. The water that runs to the sea carries much material in suspension. The earth's surface is undergoing disintegration as the result of frost and chemical action. As soon as a particle is loosened from a rock, it is subject to transportation to some other place by wind or water. The effect of water in transporting material is believed to be far greater than that of wind. In any event tremendous amounts of material in suspension are carried by water to the streams and rivers. Another large part of the water that falls to the earth soaks into the ground and absorbs a certain amount of the mineral matter from the rocks. This water seeping through the rocks will eventually reach streams and rivers and then will flow to tidal waters carrying vast quantities of solid material with it. The combination of the

material in suspension and in solution results in a large amount of continental matter that is transferred to sea areas each year.

It has been estimated that in the United States the rate of erosion is approximately 1 foot in 9,000 years. Some areas, of course, have very much more rapid rates of erosion than others, but this is the average rate at which material is carried from the area of the United States as a whole to tidal waters. The rate of erosion for the other continental areas is probably just about the same as for our country. This may not seem to be a very rapid rate, for during historic times it would amount to only about one-half a foot. The average elevation of the United States is about 2,000 feet, and so to erode all of the material lying above sea level would require something like four thousand times the total length of the historic period.

At this rate, however, something like thirty miles of erosion could have occurred during the sedimentary age. Of course, there has been no such amount of erosion as that. A particular exposed area that is undergoing erosion is worn down to sea level eventually and then erosion ceases, but it is rather remarkable that many areas which have been eroded down to sea level have in a later period been raised up again and thus other material has been subjected to erosion.

It seems probable that the average elevation of the continental areas has never been very much higher or lower than now. I believe that if there has been any change, the average elevation has been getting gradually lower. This is because the continental matter carried to tidal waters is less dense than the sub-crustal matter which moves toward the continents to restore equilibrium. The average elevation for all of the continental and island areas of the world is slightly more than 2,000 feet, less than one-half mile, but there are some parts of the earth where the elevations are three or four miles or more in height. The maximum elevation of the Himalayan Mountains is more than 29,000 feet, and there are mountain peaks in South America and Alaska which are 20,000 feet or more in elevation. There are great plateaus which stand more than two miles above sea level. But these great elevations are offset by vast areas on continents and islands which are only slightly above sea level. The ocean basins have an average depth of approximately 10,000 feet. It seems reasonably certain that some of these areas have changed their depths during the sedimentary age. Some parts of the ocean bottoms have come up, while others have gone down, but I am of the opinion that the average difference in elevation of the ocean beds and of the continents, now about two and one-half miles, has not been much less than it is now, at any time during the sedimentary period.

We can now, I believe, get an idea as to where some of the force originates which changes the configuration of the earth's surface. The water falling as rain carries off vast quantities of material in suspension and solution. It unloads certain portions of the earth's crust and overloads others. Some geologists have told us that as much as 30,000 feet, about six miles, of material have been eroded from some mountain areas. Then there are other areas on which as much as 40,000 feet, or nearly eight miles, of sediments have been placed. The earth's materials are not strong enough to resist yielding under these great negative and positive loads. There is a bending down of the crust under the sediments and a bowing up of the crust under the areas which have undergone great erosion.

The movement of material within the first five or ten miles resulting from the loading and unloading by erosion and sedimentation is not a simple one. We do not have merely a slab of material which can break or bend, but a shell approximately sixty miles in thickness completely encircling the earth. Any distortion or change in one part of this shell would have an effect on all other parts of it if the earth's crust were of tremendous strength, but such is not the case. The crust must yield under comparatively small amounts of sedimentation and erosion. If this were not true, the geodetic data would certainly enable us to detect without difficulty the extent of the masses involved. An extra load of 1,000 feet of material over the Rocky Mountain area would show up at once in the gravity data. The absence of any large differences from normal conditions leads us to believe that there is surely no excess or deficiency of material for the whole Rocky Mountain region equivalent to a blanket 1,000 feet in thickness. A blanket of even 500 feet of material is greater than can be present as an undetected excess or deficient load for an extensive area. We, therefore, may conclude, I believe, that a blanket of surface rock 500 feet in thickness over a large surface area exerts a force that is great enough to make the crust beneath yield. This yielding at times is so slow that the rocks will merely be bent and deformed, and at other times it is so rapid as to cause rocks to break.

THERMAL CHANGES IN CRUST

Isostasy is a condition of rest. When the materials of the earth's surface are carried in great amounts from one area to another during the process of erosion and sedimentation, the isostatic balance is disturbed. It is then that gravity comes into play and causes the sub-crustal material to move horizontally to restore the balance.

We have evidence to show that as much as six or eight miles of sediments have been deposited in the areas along the shores of an inland sea or the margin of an ocean. This load of material pushed the crust down into hotter regions. Each particle of crustal material reached a position several miles below the one it formerly occupied. The geoisotherms were depressed with the crustal material. Eventually, probably millions of years after the cessation of the sedimentation, the geoisotherms returned to their normal positions. In doing so, the crustal material which had been depressed increased in temperature, perhaps as much as 400°C. in extreme cases.

This increase in temperature, of course, expanded all of the crust below the sediments. The expansion tended to be cubical, that is, in all directions, but the material involved was restrained from movement except in the upward direction; hence, the result of the expansion was an uplift of the earth's surface. The amount of movement could not have been sufficient to form great mountain masses rising two or more miles high, but is it not possible that certain chemical or physical changes, other than normal expansion took place in the crustal material and that this independent expansion gave the added height to the uplifted surface? This idea is in complete harmony with isostasy and I believe it has much merit.

When an area is undergoing erosion, it is not lowered at a rate comparable with the rate of erosion. If a thousand feet of material is eroded from a mountain area, the crust below will move upward by the influx of sub-crustal material which restores the equilibrium. The crust will presumably rise up 800 or 900 feet as a result of the 1,000 feet of material taken from the surface. If a mountain area has an average elevation of about two miles, from five to ten miles of material, or even more, will have to be eroded away, if erosion is the only acting agent, before the area is brought to a low level where erosion practically ceases. During this process every cubic yard of material in the crust below the erosion area will have been brought upward five or ten miles or more into colder regions. Eventually the geoisotherms, which have been bowed upward, will resume their normal positions and in consequence each particle of the uplifted crust will become colder by several hundred degrees Centigrade. This causes contraction and the surface becomes depressed. The depression may extend even below sea level, in which case new material in the form of sediments will be deposited in the trough or basin that is formed. There is evidence that mountain areas have been elevated and depressed several times and the explanation outlined above would seem to show how this oscillation can take place.

We have seen from the above analysis what forces are being exerted on the materials of the earth. The movement downward of the crust under the sediments causes a movement of sub-crustal material back toward the region from which the sediments were derived. The horizontal movement to restore the balance must occur below and not within the crust. What the effect is of this horizontal movement of sub-crustal material on the surface configuration of the earth between the areas of erosion and sedimentation, we do not know. Some think that perhaps much of the wrinkling of the earth's surface is due to this sub-crustal flow. I am inclined to think that the movement of sub-crustal material is so small in extent that there can be little effect of it on the surface above a crust about sixty miles in thickness. I do not think there is anything like a river of material flowing from the region below the sedimentary area to the erosion area. It is more likely that the moving material involves a large volume, and any portion moves only a very short distance. I believe that this movement of sub-crustal material, which is a part of the isostatic adjustment, exerts only a minor influence on those portions of the surface of the earth which lie between the areas of sedimentation and erosion.

From the above reasoning there appear to be four definite causes of changes in the elevation of surface areas aside from the direct effects of erosion and sedimentation: First, the depression of the crustal material under an area of sedimentation; second, the moving upward of crustal material to restore the balance under an area of erosion; third, the expansion of crustal material which has been depressed by great loads of sediments; fourth, the contraction of the earth's crust and the sinking of the surface under an area of erosion. These must be the cause of many of the earthquakes of the world, although it would not be safe to assert that these are the only causes of earthquakes and surface movements.

Many geologists do not give as much weight as I do to effects of sedimentation and erosion on changes in the configuration of the earth's surface. Prof. C. K. Leith, in his splendid book entitled, *Structural Geology*, published in 1923, tells us that isostasy and the maintenance of isostatic equilibrium are minor causes of structural changes. He expresses his views as follows:

"So far as it is possible to generalize from this vague state of knowledge, it may be said that geologists are at present inclined to give principal place to changing rate of rotation and to the shrinkage of the earth, due to heat transfer from the interior outward, whether they go back to the nebular or planetesimal hypothesis of the origin of the

earth; that metamorphism and chemical changes, vulcanism, and forces tending to maintain isostatic equilibrium are regarded as subordinate or contributory causes, or perhaps as special and local expressions of the more basic causes first indicated."

Leith advises the student of the earth to be cautious in any acceptance of a simple and definite explanation as to the causes of structural changes near the earth's surface. He claims that—"The problem includes so many unmeasured and perhaps immeasurable factors that no living scientist can claim even an approximately correct perspective; all are groping for the light."

I agree with Dr. Leith that the problem involved in untangling the geological record is a very complicated one but I do not think it is wise to advise a student to avoid a simple explanation of some phenomena if other explanations are not available or if the others are so complicated as to leave one mystified and confused. I believe that the only way to attack any scientific problem is to follow a lead, no matter how simple, until evidence may show that one is not traveling in the right direction.

CONCLUSION

Isostasy is now widely recognized as a scientific principle. Its advocates hold that there is a maintenance of the isostatic equilibrium as materials are moved from one place to another over the earth's surface. These are the physical facts which are related to the processes involved in changes in the earth's surface. They have been proven by actual physical measurements. It has been stated that there are great horizontal movements in mountain areas, but that isostasy and its maintenance call for only vertical movements. My answer to this is that I recognize the horizontal movements in mountain areas, but believe that these horizontal movements are incidental to the vertical movements which are involved in maintaining the isostatic balance and which also result from the changes in the temperature of crustal matter brought about by the maintenance of equilibrium. There is an abundance of space in a mountain area for horizontal movements to occur, and it seems to me that it is easier to explain these movements as resulting from upward or downward moving material than as resulting from a shrinking interior of the earth and a collapsing crust.

Isostasy is a geological problem. It was outlined by the great geologist, C. E. Dutton. It has been used by the geodesists merely as an effective means by which to harmonize theoretical and observed

values of geodetic data. The geodesists hope that isostasy may prove of great value to geologists in their efforts to write the geological history of the earth.

ZOOLOGY.—*New crabs from the Gulf of Mexico.*[1] MARY J. RATHBUN, United States National Museum.

During the past year two noteworthy species of crabs were discovered in the Gulf of Mexico. One, taken in deep water during explorations by the Carnegie Laboratory at Tortugas, is a second species of *Benthochascon*, a genus known previously from the Indian Ocean; the other was obtained by the Caribbean Biological Laboratories on the coast of Mississippi.

Family PORTUNIDAE

Benthochascon schmitti, new species

Carapace considerably broader than long, anterior portion with an arcuate outline, the long postero-lateral margins gradually convergent; surface covered with a pavement of flat close set granules; regions fairly well indicated; hepatic region elevated, mesogastric outlined; deep thumb nail impressions either side of urogastric region and of posterior cardiac region; on the branchial region a sublongitudinal ridge through the middle and a blunt sinuous ridge following the curve of the cervical suture. Antero-lateral margin armed with three long stout equidistant spines, the first or orbital spine directed forward, the others obliquely outward; the third, at the lateral angle, the longest and most erect. Four short spines or teeth on front, sinuses U-shaped, median narrower than lateral. A small emargination and a short groove at middle of supra-orbital margin; a broad sinus and trace of a groove just within the outer spine. A long slender spine at inner angle of suborbital margin is produced about as far as front; from this spine the margin slopes backward to a small notch and groove at base of outer spine.

Buccal cavity much broader than long, anteriorly widened; merus of third maxilliped produced outward, angle arcuate. Cheliped shorter than ambulatories; a spine at inner end of ischium; two spines on merus, one distad of middle of upper margin, the other at distal third of lower margin; carpus with a long spine at inner angle, a smaller one at outer angle; a spine at distal end of upper margin of palm; palm obscurely ridged, two ridges above, two below, one through middle of outer and of inner surface. Ambulatory legs rather narrow, meri enlarged at middle; merus of swimming leg with parallel sides; propodus flattened, elongate, upper margin twice as long as height; dactylus narrow-lanceolate. Male abdomen constricted between fifth and sixth segments, the latter twice as broad as long, side margins arcuate; terminal segment broadly triangular.

Color.—Carapace ochraceous buff except on hinder half of middle two-thirds, which is olive buff strongly tinged with hair brown. Marginal spines basally carapace color, next whitish, distal half ochraceous buff, extreme tips

[1] Published with the permission of the Secretary of the Smithsonian Institution. Received February 3, 1931.

lighter. Antennae, antennules, rostral and suborbital spines china white, margins of orbit a sort of ochraceous buff, eye stalks ferruginous, corneae silvery black around margins. Maxillipeds white. Chelipeds china white

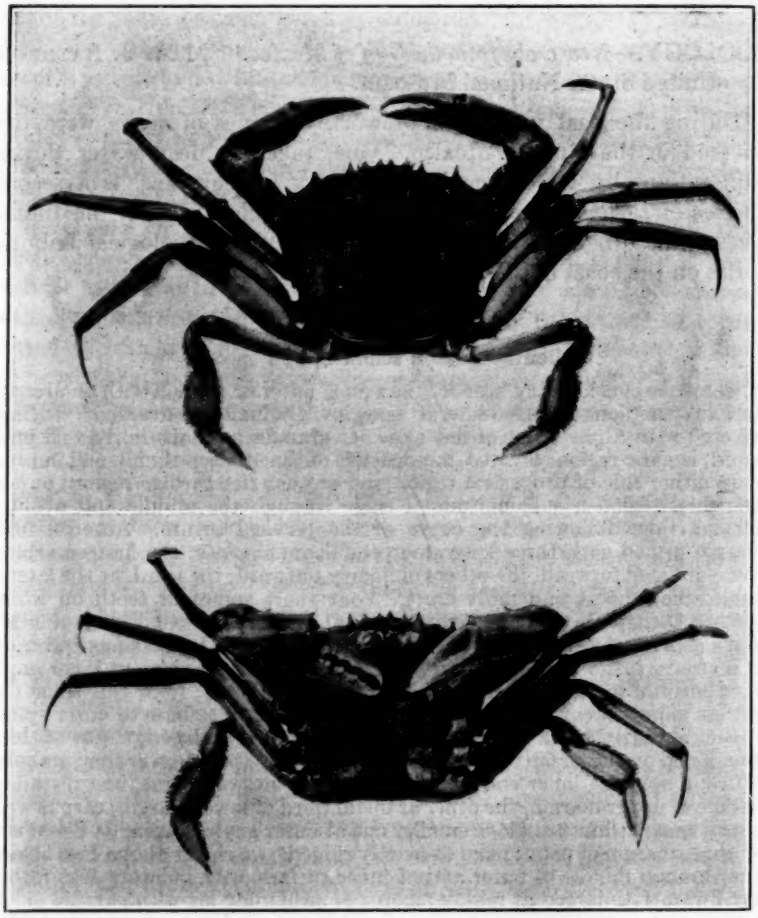

Plate 1. *Benthochascon schmitti*, ♂ holotype, carapace 67 mm. wide. Dorsal and ventral views.

except anterior third of sides and distal under edge of merus red and under side of coxae white suffused with pinkish vinaceous to peach blossom pink. Legs proximally white; running from distal half of merus in hind leg to distal fourth in front leg, the legs are bright scarlet vermilion except on inside of groove of carpus and propodus of first and second ambulatories which is

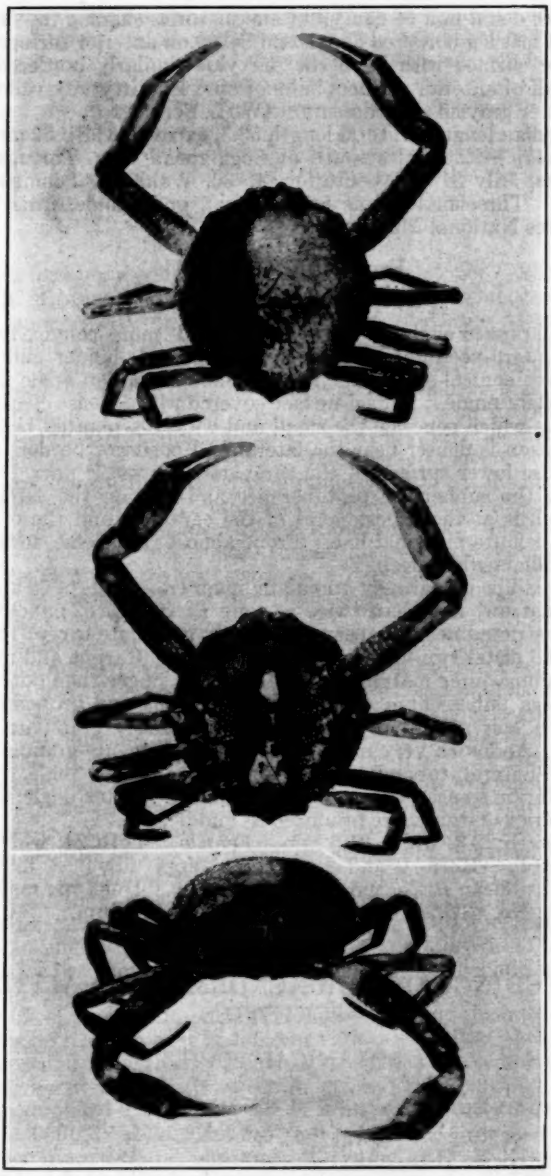

Plate 2. *Persephona crinita*, ♂ holotype, carapace 21.6 mm. wide, hair removed from right half. Dorsal, ventral, and front views.

bluish white; distal half of dactyli of ambulatories shading into wax yellow; propodus of last leg bordered above and below on anterior surface and below on posterior surface with lilac, the dactylus similarly bordered below on proximal half of anterior surface; hairs of hind leg dirty wax yellow. Under parts a fainter grayish than dorsum. (W. L. SCHMITT.)

Male, median length 51, total length 53.3, extreme width 67 mm.

Type-locality.—22.3 miles south of Loggerhead Key, Tortugas, Florida, 180 fathoms, July 31, 1930, Station 37–30, Waldo L. Schmitt, Carnegie Institution. Three males (one is holotype), one female, Cat. No. 63738, United States National Museum.

Family LEUCOSIIDAE

Persephona crinita, new species

Male.—Carapace slightly longer than broad, more convex from side to side than antero-posteriorly; front little produced; hinder end with three similar, short, conical spines, the median one forming an angle not much in excess of a right angle. Dorsal surface covered with a dense coating of short, hooked hairs which conceals the small and widely separated bead granules; the granulation is denser near the lateral and posterior borders and is continued on the lower surface of the carapace where it is finer. A granular tubercle on the subhepatic protuberance and two on the lateral margin, one of which is at the widest point of the carapace and the other antero-lateral; no definite marginal line. Front almost transverse, forming a very wide V, median sulcus deep.

Outer maxillipeds sparingly granulate, inner two-thirds of ischium smooth. Chelipeds narrow, less than twice as long as carapace, pubescent; merus slightly constricted near the carpus, coarsely granulate except for a smooth patch on the distal two-fifths, above and below. Carpus and manus finely granulate along outer margin; dactylus a little longer than outer margin of manus. Legs pubescent above on merus, carpus and propodus; dactylus fringed with hair on either side. Sternum coarsely granulate, interstices pubescent. Abdomen very narrow, first three segments granulate.

Female.—Lateral tubercles less prominent than in male, obsolescent; lateral posterior spines further apart, forming a greater angle with median spine; posterior margin more produced at middle.

Male, length 22.3, width 21.6 mm. Female, length 24, width 22.8 mm.

Type-locality.—Horn Island Pass, Mississippi, about 3 fathoms, Aug. 20, 1930, Caribbean Biological Laboratories Inc. Holotype male, paratype female, Cat. No. 63739, United States National Museum.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

BOTANICAL SOCIETY

226TH MEETING

The 226th meeting was held at the Cosmos Club May 6, 1930.

Program: H. B. HUMPHREY: *Regeneration in some conifers* (illustrated). Regeneration from stump sprouts, common in deciduous forest trees, is rare among conifers. The redwood, *Sequoia sempervirens*, is known to reëstablish

itself in this way after a fire. *Pinus rigida*, *P. taeda*, loblolly pine; *P. serotina*, pond or marsh pine, and *P. palustris*, long-leaf, yellow or Georgia pine, are found to regenerate by means of stump shoots and from buds beneath the bark in fire-swept trees. (*Author's abstract.*)

This paper was followed by *New Woods for old*, a one reel moving picture, from the Forest Service.

E. P. KILLIP: *Across the Andes and on the Amazon for cube and other plants* (illustrated).—An abstract of this paper, appears in the Proceedings of the Biological Society, this JOURNAL **14**: 352. 1930.

227TH MEETING

The 227th meeting was held at the Cosmos Club October 7, 1930.

Dr. H. B. HUMPHREY presented a brief note on the influence of trees and associated undergrowth on the rate of stream discharge as observed and recorded by him in the vicinity of his home northwest of Washington.

Program. H. B. HUMPHREY: *The relation of weather to the development of stem rust Puccinia graminis* (address of the retiring president, illustrated).—Our modern knowledge of plant rusts dates from MICHELI who, in 1730, described and illustrated the first genus, *Puccinia*. PERSOON, in 1795, first recognized the rusts as a separate group of fungi. DEBARY'S discovery of the phenomenon of heteroecism in 1865 added to our knowledge of the life history of stem rust, *Puccinia graminis*. In 1927, CRAIGIE discovered the rôle of the pycniospores in the life cycle of stem rust and sunflower rust. These steps in the life history of the stem rust require certain meteorologic conditions such as humidity, temperature, light, atmospheric movement, etc. Concert of all these factors is necessary to the development of an epiphytotic of any one of the cereal rusts.

Comparison of stem-rust epiphytotic summers with those characterized by little or almost no rust, over a long series of years, has shown that the ultimate effect on the host of an optimum of soil moisture and abundant rust is less pronounced than it is under conditions of equal rustiness accompanied by inadequate soil moisture. One of the effects of the rust attack is a marked increase in the water requirement of the afflicted host. An adequate supply of soil moisture meets this increased demand and has a tendency to sustain the photosynthetic vigor of the host. The optimum temperature for germination of teliospores of *Puccinia graminis* lies between 12° and 20°C.; that of the sporidia, between 15° and 20°C.; that of the aeciospores, between 5° and 18°C.; and that of the urediniospores, between 20° and 25°C. It is probable that spore showers falling over the spring-wheat and the hard-red-winter-wheat States in May sometimes result in early infection. If the temperature at the time be suboptimum the growth of the fungus is inhibited. These primary infections later become the foci from which urediniospores initiate secondary infection and spread of rust.

Light is one of the most important variables affecting the incidence of stem rust. It has been shown that in different varieties of wheat there are important differences in stomatal response to light and that these differences are in some varieties correlated with susceptibility to the organism. This fact is especially exemplified in such varieties of wheat as the rust-susceptible Little Club and the highly resistant Hope.

It has been proved that *Puccinia graminis* overwinters successfully in the Gulf States and in California, Oregon, and Washington. Repeated observations over many years have established the fact that with the northward

march of the optimum conditions for rust development there is a corresponding northward movement of urediniospores. The origin of an epiphytotic in the spring-wheat States is not, however, to be found solely in any such south-to-north march of inoculum. We must take into the reckoning the common barberry of which there yet remain in the North-Central States uncounted thousands of bushes. Every spring these bushes discharge into the surrounding atmosphere countless billions of aeciospores which initiate local outbreaks and probably play a considerable part in furnishing initial inoculum for the general, far-flung epiphytotics that from time to time befall the spring-wheat States.

The speaker has recorded, during several crop seasons, convincing circumstantial evidence to the effect that, in addition to the spore showers precipitated by south winds which during the growing season occasionally carry urediniospores northward, there are spore showers of another kind, precipitated by rainfall from the clouds of major cyclonic storms that occasionally travel in an easterly or northeasterly direction across the North-Central States and out to the Atlantic Ocean by way of the St. Lawrence Valley. Although it yet remains definitely to be proved that these transcontinental cyclonic storms are factors in the distribution of rust spores, the theory of such distribution is sound. It may safely be assumed that aeciospores and urediniospores, set free from infected barberry bushes and from grains and grasses, rise on convection currents to great heights, to be swept later into the vortex of the approaching storm only to be precipitated by rain. We know that such spores have been collected by exposing spore traps at elevations of 10,000 feet above the Mississippi Valley. If caught by rain they cannot escape precipitation and, under conditions of humidity suitable to their prompt germination, can cause infection if light and temperature are favorable. (*Author's abstract.*)

L. H. FLINT, *Recording Secretary.*

Obituary

HOWARD LINCOLN HODGKINS, dean and professor of mathematics at George Washington University, died on Friday, February 13, 1931, following a long illness. He was born in Elgin, Ill., but came to Washington in his youth. He graduated from George Washington University, then called Columbian University, in 1883 and later received the degrees of bachelor of arts, master of arts, doctor of philosophy and doctor of science. From 1882 to 1892 he served as special computer in the Nautical Almanac Office. He had been connected with George Washington University since 1883, holding the positions of professor of mathematics and physics, dean of the department of arts and sciences, dean of the college of engineering, and dean of the Corcoran Scientific School. He was appointed acting president in 1920 and served as president from 1921 to 1923. He was a member of the Washington Academy of Sciences, the Philosophical Society of Washington, the American Mathematical Society, the Mathematical Association of America, and the American Association for the Advancement of Science.